

## CHAPTER 3

### WATER TREATMENT PROCESSES

3-1. Process selection factors. The design of treatment facilities will be determined by considering all engineering, labor, materials, equipment, and energy factors.

3-2. Preliminary treatment processes. Surface waters typically contain fish and debris which can clog or damage pumps, clog pipes, and cause problems in water treatment. Surface waters may also contain high concentrations of suspended matter. Preliminary treatment is employed for removal of debris and part of the suspended materials.

#### a. Screens.

(1) Coarse screens or racks. Coarse screens, often termed bar screens or racks, must be provided to intercept large, suspended or floating material. Such screens or racks are made of 1/2-inch to 3/4-inch metal bars spaced to provide 1 to 3 inch openings.

(2) Fine screens. Surface waters require screens or strainers for removal of material too small to be intercepted by the coarse rack. These may be basket-type, in-line strainers, manually or hydraulically cleaned by backwashing, or of the traveling type, which are cleaned by water jets. Fine-screen, clear openings should be approximately 3/8 inch. The velocity of the water in the screen openings should be less than 2 fps at maximum design flow through the screen and at minimum screen submergences which occur at minimum anticipated flows.

(3) Ice clogging. In northern areas, screens may be clogged by frazil or anchor ice. Exposure of racks or screens to cold air favors ice formation on submerged parts and should be avoided to the maximum practicable extent. Steam or electric heating, diffusion aeration, and flow reversal have been used to overcome ice problems.

(4) Disposal of screenings. Project planning must include provisions for the disposal of debris removed by coarse and fine screens.

b. Flow measurement. Water treatment processes, such as chemical application, are related to the rate of flow of raw water. Therefore, it is essential that accurate flow-rate measurement equipment is provided. Pressure differential devices of the Venturi type are commonly used for measurement of flow in pressure conduits. An alternative selection for pressure conduits is a magnetic flow meter if the minimum velocity through the meter will be 5 fps or more. A Parshall flume can be used for metering in open channels. Flow signals from the metering device selected should be transmitted to the treatment plant control center.

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c. Flow division. While not a treatment process, flow division (flow splitting) is an important treatment plant feature that must be considered at an early stage of design. To insure continuity of operation during major maintenance, plants are frequently designed with parallel, identical chemical mixing, and sedimentation facilities. No rigid rules can be given for the extent of duplication required because a multiplicity of factors influence the decision. Normally, aerators are not provided in duplicate. Presedimentation basins may not require duplication if maintenance can be scheduled during periods of relatively low raw water sediment load or if the following plant units can tolerate a temporary sediment overload. If it is determined that presedimentation at all times is essential for reliable plant operation, then the flow division should be made ahead of the presedimentation basins by means of identical splitting weirs arranged so that flow over either weir may be stopped when necessary. During normal operation, the weirs would accomplish a precise equal division of raw water, regardless of flow rate, to parallel subsequent units: rapid-mix, slow-mix, and sedimentation. The water would then be combined and distributed to the filters. If presedimentation units are not provided, then the flow is commonly split ahead of the rapid-mix units. If flow division is deemed necessary, the design should allow flexibility in construction such that at least one system, or train, of units can be constructed first. Duplicate trains can then be constructed after the first train is in operation.

d. Sand traps. Sand traps are not normally required at surface water treatment plants. Their principal application is for the removal of fine sand from well water. The presence of sand in well water is usually a sign of improper well construction or development. If sand pumping cannot be stopped by reworking the well, the sand must be removed from the well water. Otherwise, it will create serious problems in the distribution system by clogging service pipes, meters, and plumbing. Centrifugal sand separators provide an effective means of sand removal.

e. Plain sedimentation. Plain sedimentation, also termed "presedimentation," is accomplished without the use of coagulating chemicals. Whether plain sedimentation is essential is a judgment decision influenced by the experience of plants treating water from the same source. Water derived from lakes or impounding reservoirs rarely requires presedimentation treatment. On the other hand, water obtained from notably sediment-laden streams, such as those found in parts of the Midwest, require presedimentation facilities for removal of gross sediment load prior to additional treatment. Presedimentation treatment should receive serious consideration for water obtained from rivers whose turbidity value frequently exceeds 1,000 units.

(1) Plain sedimentation basins. Plain sedimentation or presedimentation basins may be square, circular, or rectangular and are equipped with sludge removal mechanisms.

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(2) Design criteria. Detention time should be approximately 3 hours. Basin depth should be in the approximate range of 10 to 15 feet, corresponding to upflow rates of 600 to 900 gpd per square foot. Short-circuiting can be minimized by careful attention to design of inlet and outlet arrangements. Weir loading rates should not exceed approximately 20,000 gpd per foot. Where presedimentation treatment is continuously required, duplicate basins should be provided.

3-3. Aeration. The term "aeration" refers to the processes in which water is brought into contact with air for the purpose of transferring volatile substances to or from the water. These volatile substances include oxygen, carbon dioxide, hydrogen sulfide, methane, and unidentified volatile organic compounds responsible for tastes and odor. Aeration is frequently employed at plants designed for iron and manganese removal. The oxygen added by aeration oxidizes dissolved iron and manganese to insoluble forms which can then be removed by sedimentation and filtration.

a. Purposes of aeration. The principal objectives of aeration are:

(1) Addition of oxygen to water for the oxidation of iron, manganese, and hydrogen sulfide and to a limited extent, organic matter.

(2) Partial removal of substances that may interfere with or add to the cost of water treatment. Examples: Removal of hydrogen sulfide prior to chlorination; removal of carbon dioxide prior to lime softening.

(3) Reduction of the concentration of taste-and-odor producing substances such as hydrogen sulfide, and to a limited extent, volatile organic compounds.

b. Types of aerators. Three types of aerators are commonly employed. These are: (1) waterfall aerators exemplified by spray nozzle, cascade, and multiple-tray units, (2) diffusion or bubble aerators which involve passage of bubbles of compressed air through the water, and (3) mechanical aerators employing motor-driven impellers alone or in combination with air injection devices. Of the three types, waterfall aerators, employing multiple trays, are the most frequently used in water treatment. The efficiency of multiple-tray aerators can be increased by the use of enclosures and blowers to provide counterflow ventilation. The use of diffusion or bubble aerators will be discouraged because of the complexity of compressed air equipment.

c. Use of aeration. Aeration will be considered only when treating ground water with high levels of dissolved iron, manganese, hydrogen sulfide, or other dissolved gases and volatile organic compounds which create odor or taste problems. Aeration will be considered for the

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removal of carbon dioxide in ground water if lime softening is to be used. A laboratory test to determine the efficiency of aeration is usually required.

3-4. Coagulation and flocculation. Coagulation means a reduction in the forces which tend to keep suspended particles apart. The joining together of small particles into larger, settleable, and filterable particles is flocculation. Thus, coagulation precedes flocculation, and the two processes must be considered conjunctively.

a. Purposes of coagulation and flocculation. Raw water supplies, especially surface water supplies, often contain a wide range of matter, including minerals, organic substances, and microscopic organisms ranging in size from about 0.001 to 1.0 micrometer. Particles in this size range are often referred to as "colloidal" particles. Larger particles, such as sand and silt, readily settle out of water during plain sedimentation, but the settling rate of colloidal particles is so low that removal of colloidal particles by plain sedimentation is not practicable. Chemical coagulation and flocculation processes are required to remove these smaller particles in sedimentation basins.

b. Chemical coagulants. The most frequently used chemical coagulant is aluminum sulfate:  $(\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O})$ , which averages about 17 percent  $\text{Al}_2\text{O}_3$  and is also called "alum" or "filter alum." Other aluminum compounds used as coagulants are potash alum and sodium aluminate, principally the latter. Other coagulants include ferric sulfate, chlorinated copperas (ferrous sulfate), and ferric chloride. Organic polyelectrolyte compounds, alone or in combination with conventional chemical coagulants, are also employed. The coagulation-flocculation processes are accomplished step-wise by short-time rapid mixing to disperse the chemical coagulant followed by a longer period of slow mixing to complete the flocculation process. Laboratory jar tests will normally be performed to determine the type and quantity of coagulant(s) best suited to the water requiring treatment.

c. Design criteria for mixing. Criteria for rapid- and slow-mix processes have been developed on the basis of detention time, power input, velocity gradient (G) and the product (Gt) of velocity gradient and detention time. The values of G and Gt are computed from the following equations:

$$G = \left( \frac{P}{uV} \right)^{1/2}$$

$$Gt = \frac{1}{Q} \left( \frac{PV}{u} \right)^{1/2}$$

and

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where:

Gt = product of G and t, a dimensionless number

G = velocity gradient (fps/foot; or second<sup>-1</sup>)

P = the power dissipated in the water (ft-lb/second)

u = water viscosity (pound<sub>f</sub>-seconds/square feet) ( $u = 2.73 \times 10^{-5}$  at 50 degrees F.)

Q = flow through the sedimentation unit (cfs)

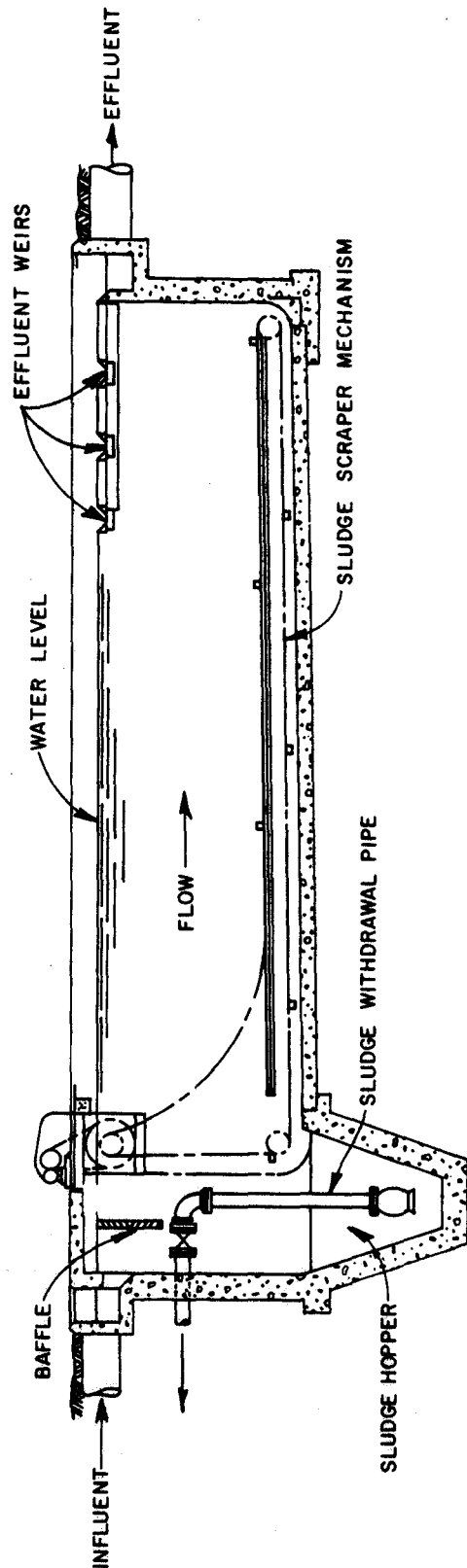
V = volume of mixing basin (cubic feet)

t = mixer detention time (seconds)

(1) Rapid mixing. The coagulant is introduced into the water by rapid mixing and coagulation is initiated. Detention periods for rapid-mix units usually range from 10 to 30 seconds with installed mixer power approximately 0.25 to 1.0 hp per mgd. Power and detention time should be matched so that values of G will be in the approximate range: 500 to 1,000/second. A wire-to-water efficiency of 80 percent, a water temperature of 50 degrees F., a power input of 1.0 hp per mgd and a detention time of 10 seconds, yield a G value of about 1,000/second and a Gt value of 10,000. Similarly, a 30-second detention time gives a G value of about 600 and a Gt value of 18,000. Long detention periods for rapid-mix basins should be avoided because of higher power requirements and inferior coagulation results. The rapid-mix basin should be designed to minimize short circuiting.

(2) Slow mix. Flocculation is accomplished by slow mixing. Detention periods should range from 30 minutes to 60 minutes, with installed mixer power of approximately 0.1 to 3.5 hp per mgd. G values in the range of 20/second to 100/second are commonly employed. Corresponding Gt values will, therefore, be in the range of 36,000 to 360,000. Tapered, slow mixing with G decreasing from a maximum of about 90/second down to 50/second and then to 30/second can be used and will generally produce some improvement in flocculation. Somewhat higher G values, up to 200/second, are employed in some water softening plants. For normal flocculation, using alum or iron salts, the maximum peripheral speed of the mixing units should not exceed about 2.0 fps and provisions should be made for speed variation. To control short circuiting, two to three compartments are usually provided. Compartmentation can be achieved by the use of baffles. Turbulence following flocculation must be avoided. Conduits carrying flocculated water to sedimentation basins should be designed to provide velocities of not less than 0.5 fps and not more than 1.5 fps. Weirs produce considerable turbulence and should not be used immediately following flocculation.

3-5. Sedimentation basins. Sedimentation follows flocculation, and the most common types of sedimentation basins in general use are shown in figures 3-1 and 3-2. A minimum of two basins should be provided to allow one unit to be out of service for repair, but construction of the second unit may be delayed until the first unit is operational. The



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FIGURE 3-1. RECTANGULAR SEDIMENTATION BASIN

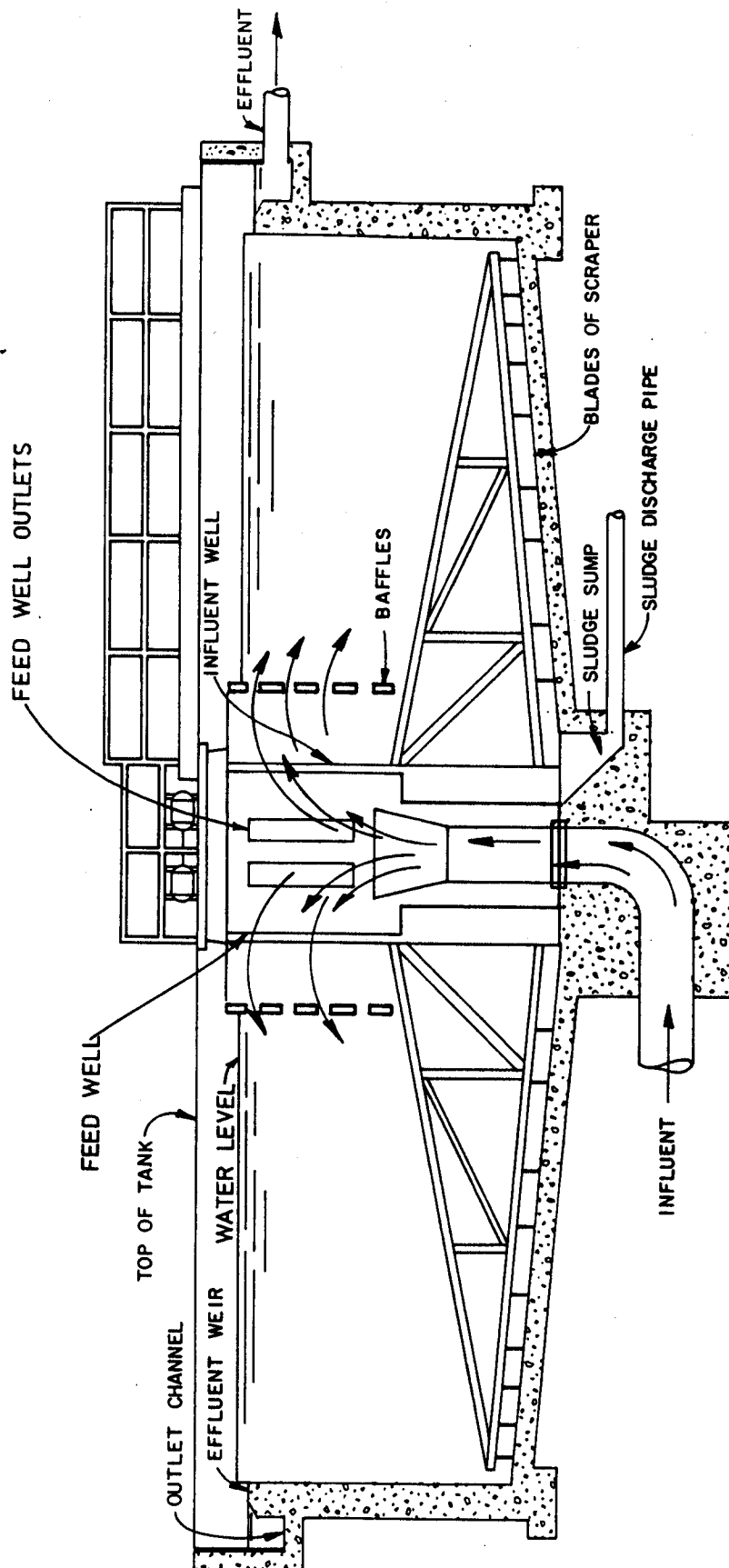


FIGURE 3-2. CIRCULAR SEDIMENTATION BASIN

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design must include arrangements that permit use of a single basin when necessary.

a. Design criteria. Basins may be rectangular, square, or circular in plan. Basin depths generally are from 10 to 16 feet. Under comparable conditions, deeper basins usually perform better than shallow ones. In general, the basins should be sized to provide a minimum detention time of 2 to 4 hours. For conventional coagulation plants, basin overflow rates commonly range from roughly 500 to 1,500 gpd per square foot with weir loading rates at 20,000 gpd per foot or less. Higher overflow rates may be used at some plants employing upflow clarification units. Sedimentation basin inlets, outlets, and baffles must be carefully designed to minimize short circuiting. The solids (sludge) which settle to the bottom of the basin must be removed before the depth of the sludge becomes great enough to interfere with effective sedimentation. In general, mechanical sludge removal equipment is a requirement. All basins must be provided with drains and overflows. Basin covers, usually in the form of a superstructure, will be required in northern localities where ice is a problem.

b. Flocculation-sedimentation basins. Units of this type, usually circular, combine the functions of flocculation, sedimentation, and sludge removal. Flocculation is accomplished in a circular center well. Sedimentation occurs in the annular space between the flocculation section and the perimeter effluent weir. Design criteria are generally similar to those applicable to separate units.

c. Suspended solids contact basins. Basins of this type combine rapid-mixing, flocculation, sedimentation, and sludge removal in a single unit. Coagulation and flocculation take place in the presence of a slurry of previously formed precipitates which are cycled back to the mixing and reaction zone. Upflow rates at the point of slurry separation should not exceed about 1.0 gpm per square foot for units used as clarifiers following coagulation.

3-6. Filtration. Filtration of water removes colloidal and larger particles from water by passage through a porous medium, usually sand or granular coal. The suspended particles removed during filtration range in diameter from about 0.001 to 50 micrometers and larger. Several different types of medium arrangements and rates of flow through filters can be used. The filtration process most commonly used is rapid-sand filtration, but pressure filters and diatomite filters are used at smaller installations.

a. Rapid sand filters.

(1) Filtration rate. Rapid sand filters commonly operate at rates between approximately 2 and 8 gpm per square foot. The usual rate is about 3 to 5 gpm per square foot. Adequate pretreatment and filter design will allow application rates of up to 6 gpm per square



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foot with little difference in water quality. If high rates are to be used in design, great care must be taken to insure that all prefiltration treatment processes including coagulation, flocculation, and sedimentation will perform satisfactorily and consistently. High-rate filter operation definitely requires excellence in pre-filtration treatment, especially in the case of surface waters. It is recommended that data from laboratory or pilot studies be utilized whenever possible rather than an arbitrary selection of criteria.

(2) Filter medium.

(a) Sand. Silica sand is the most commonly used filter medium and its depth should be at least 24 inches and not more than 30 inches. When sand is employed, its "effective size" should fall in the range of 0.35 to 0.5 millimeter with a uniformity coefficient of 1.3 to 1.7. Filter sand usually ranges in size from that passing a 16-mesh (U.S. Series) sieve to that retained on a 50-mesh (U.S. Series) sieve. Approximately 100 percent by weight of the sand should pass the 16-mesh sieve and 90 to 100 percent be retained on a 50-mesh sieve. Filter sand should be clean silica sand having a specific gravity of not less than 2.5. The hydrochloric acid solubility of the sand should be less than 5 percent.

(b) Anthracite. Anthracite is an alternative medium consisting of hard anthracite coal particles. Its depth is usually between 8 inches and 3 feet. The effective size commonly ranges from about 0.45 millimeter to 0.6 millimeter with a uniformity coefficient not to exceed 1.7. The hardness should not be less than 2.7 on the Moh scale and the specific gravity not below 1.4. Also, the anthracite should be visibly free of clay, shale, and dirt.

(c) Multimedia. Multimedia filters employ two or three layers of media of different size and specific gravity. A common arrangement, the dual media filter, is 20 inches of anthracite overlaying a sand layer of approximately 8 to 12 inches. The anthracite layer has a size range of about 0.8 to 2.0 millimeter; the sand layer, about 0.4 to 1.0 millimeter. Tri-media filters employ an 18-inch anthracite layer, an 8-inch sand layer, and an underlying 4-inch layer of garnet or ilmenite having a size range of 0.2 to 0.4 millimeter. Garnet has a specific gravity of about 4 and ilmenite about 4.5.

(3) Filter gravel and underdrains. The filter media is commonly supported by a 10 to 18-inch layer of coarse sand and graded gravel. The gravel depth may range from 6 to 24 inches, depending on the filter underdrain system chosen. The gravel should consist of hard, rounded stones having a specific gravity of at least 2.5 and a hydrochloric acid solubility of less than 5 percent. A 3 to 4-inch transition layer of coarse (torpedo) sand, having a size range of about .05 to 0.1 millimeter, is placed on top of the filter gravel. Gravel size usually

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ranges from about 0.1 inch to about 2.5 inches; fine material then increasingly coarser material in the direction of flow for filtration. Filter underdrains may be constructed of perforated pipe grids or various commercial underdrain systems.

(4) Number of filters. Not less than two filters should be installed regardless of plant size. For large plants, rough guidance as to the number of filters to be provided may be obtained from the following equation:

$$N = 2.7 (Q)^{1/2}$$

where:

N = number of filter units

Q = design capacity in mgd

Thus, a 9 mgd plant would require eight filters.

(5) Size of filter units. The maximum filter size is related to wash water flow rate and distribution. Normally, individual filter sizes do not exceed about 2,100 square feet corresponding to a capacity of about 6 mgd at a flow rate of 2.0 gpm per square foot. A unit of this size would require a maximum backwash water rate of about 60 mgd, which is excessive. Consequently, it should be divided into two parts of equal size arranged for separate backwashing. Total filter box depth should be at least 9 feet.

(6) Filter backwash. Backwash facilities should be capable of expanding the filter media 50 percent. This will require wash rates in the range of 10 to 20 gpm per square foot. Backwash water can be supplied by a backwash pump or from elevated storage provided specifically for this purpose. Filter down-time during wash periods commonly average 10 to 20 minutes including a 5- to 15-minute wash period. For a 15-minute backwash of a single unit, at maximum rate, the wash water volume will be 300 gallons per square foot of filtration area in that unit. This aids in cleaning the filter and is commonly accomplished by rotary or fixed surface-wash equipment located near the top of the bed. It is operated for a time period equal to that of the backwash. Water pressures of 40 to 100 psi are required for surface-wash operation at a rate of 0.5 gpm per square foot. If an independent wash water storage tank is used, it must refill between washes. Tank capacity should be at least 1.5 times the volume required for a single wash.

(7) Wash water troughs. Wash water troughs equalize the flow of wash water and provide a conduit for removal of used water. Two or more troughs are usually provided. The elevation of the trough bottoms should be above that of the expanded bed. The clear horizontal distance between troughs should not exceed 5 to 6 feet, and the top of

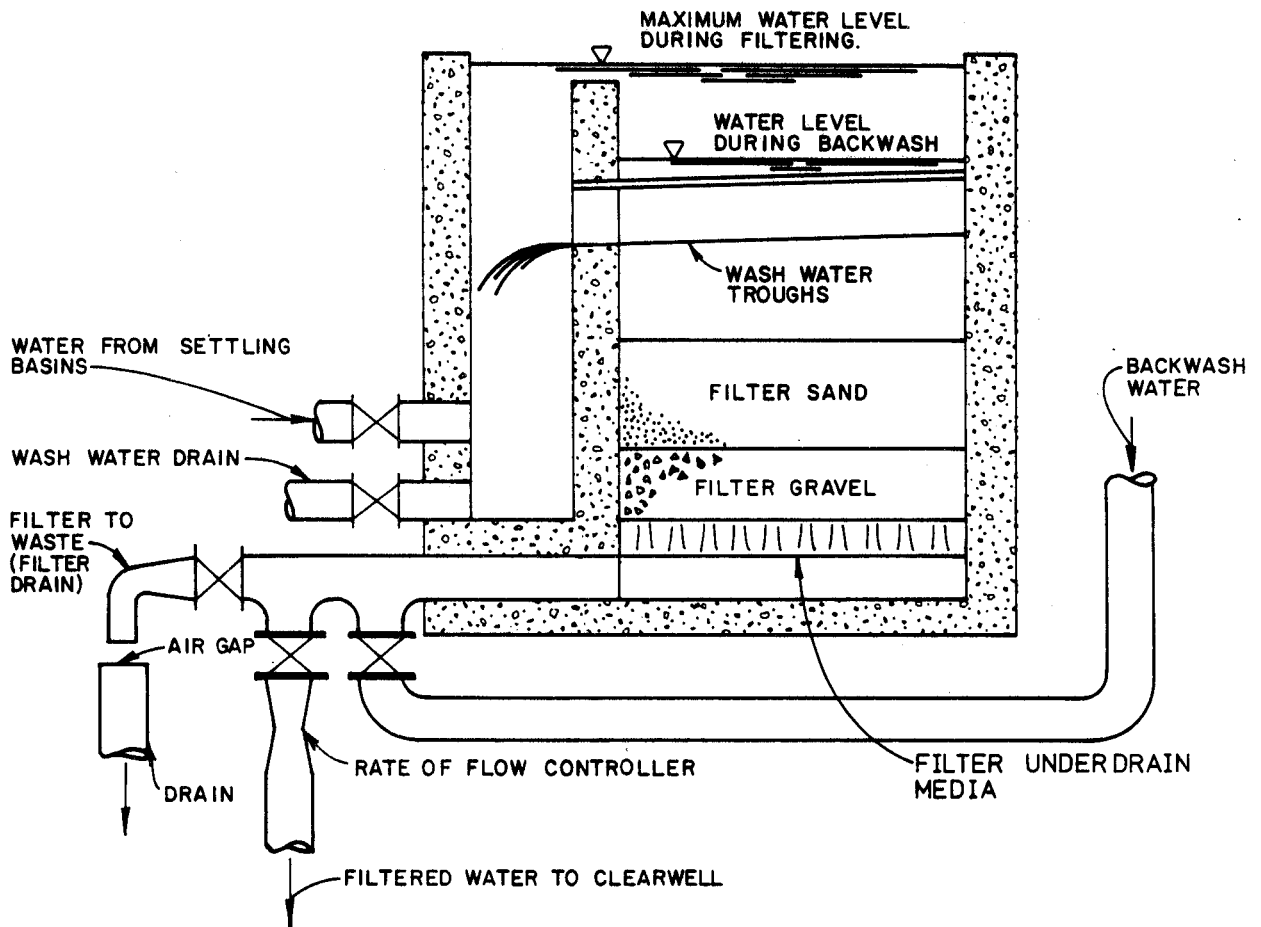
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the troughs not more than 30 inches above the top of the non-expanded bed.

(8) Filter piping and equipment. Essential filter control valves, etc., are shown schematically in figure 3-3. Each filter should be equipped with a rate-of-flow controller plus associated equipment for automatic filter water-level control. The latter senses the water level in the main influent conduit and transmits a signal to the flow controllers. The controllers, in response to this signal, adjust filtration rates to match the inflow from the sedimentation basins. Thus, within practical limits, total filter outflow always equals total inflow and the filter water level remains virtually constant. A device that will sense maximum permissible clearwell level should also be provided. This should be arranged so that at maximum allowable clearwell water level a shut-off signal will be transmitted to all filter controllers and also to an audible alarm. Other designs, not involving rate controllers, such as "influent flow splitting" and "variable declining rate" have been developed and may be employed at the discretion of the designer. In general, each filter must have five operating valves: influent, wash water, drain, filtered water, and filter-to-waste. It is emphasized that the filter-to-waste piping must not be directly connected to a plant drain or sewer. An effluent sampling tap must be provided for each filter. Valves can be manually, electrically, hydraulically, or pneumatically operated. Butterfly type valves are recommended for filter service. Design velocities commonly employed for major filter conduits are as follows:

<u>Conduit</u>	<u>Design Velocity</u> <u>fps</u>
Influent	1-4
Filtered water	3-6
Wash water	5-10
Drain	3-8
Filter-to-waste	6-12

The filtered water conduit must be trapped to prevent backflow of air and provide a seal for the rate controllers. The filter pipe gallery should have ample room, good drainage, ventilation, and lighting. Dehumidification equipment for the gallery should receive consideration. Filters should be covered by a superstructure except under favorable climatic conditions. Drainage from the operating floor into the filter should be prevented by a curb. Access to the entire bed should be provided by a walkway at operating floor level around the filter. Filters may be manually or automatically controlled from local or remote locations. Facilities permitting local, manual control are recommended irrespective of other control features. Used backwash water should be discharged to a wash water recovery basin or to a waste disposal facility. Regulatory agencies generally view filter wash



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FIGURE 3-3. SCHEMATIC OF RAPID SAND FILTER OPERATIONAL CONTROLS

water as a pollutant and forbid its direct discharge to the natural drainage.

(9) Essential instrumentation. Minimum essential instrumentation for each filter will be provided as follows: rate-of-flow indicator, loss-of-head indicator, wash water rate-of-flow indicator, and totalizing meter. If a wash water storage tank is provided, it must be equipped with a water-level indicator.

b. Pressure filters. Pressure filters are similar in construction and operating characteristics to rapid sand filters; however, in a pressure filter the media, gravel bed, and underdrains are enclosed in a steel shell. An advantage of a pressure filter is that any pressure in the waterlines leading to the filter is not lost, as in the case of gravity filters, but can be used for distribution of the filtered water. Between 3 and 10 feet of pressure head are lost through the filter. The primary disadvantage of a pressure filter is that, due to the filter being enclosed in a steel shell, access to the filter bed for normal observation and maintenance is restricted. Also, the steel shells require careful periodic maintenance to prevent both internal and external corrosion. The use of pressure filters is not advantageous in most systems; however, if the pressure requirements and conditions in a particular system are such that repumping of filtered water can be eliminated, cost savings will be realized.

3-7. Disinfection. Disinfection involves destruction or deactivation of organisms which may adversely affect the health of the water consumer. The preferred method of disinfecting water supplies is by application of chlorine to water (chlorination).

a. Definitions. Terms frequently used in connection with chlorination practices are defined as follows:

(1) Chlorine demand. The difference between the concentration of chlorine added to the water and the concentration of chlorine remaining at the end of a specified contact period. Chlorine demand varies with the concentration of chlorine applied, time of contact, temperature, and water quality.

(2) Chlorine residual. The total concentration of chlorine remaining in the water at the end of a specified contact period.

(3) Combined available residual chlorine. Any chlorine in water which has combined with nitrogen.

(4) Free available residual chlorine. That part of the chlorine residual which has not combined with nitrogen.

b. Chlorination practice.

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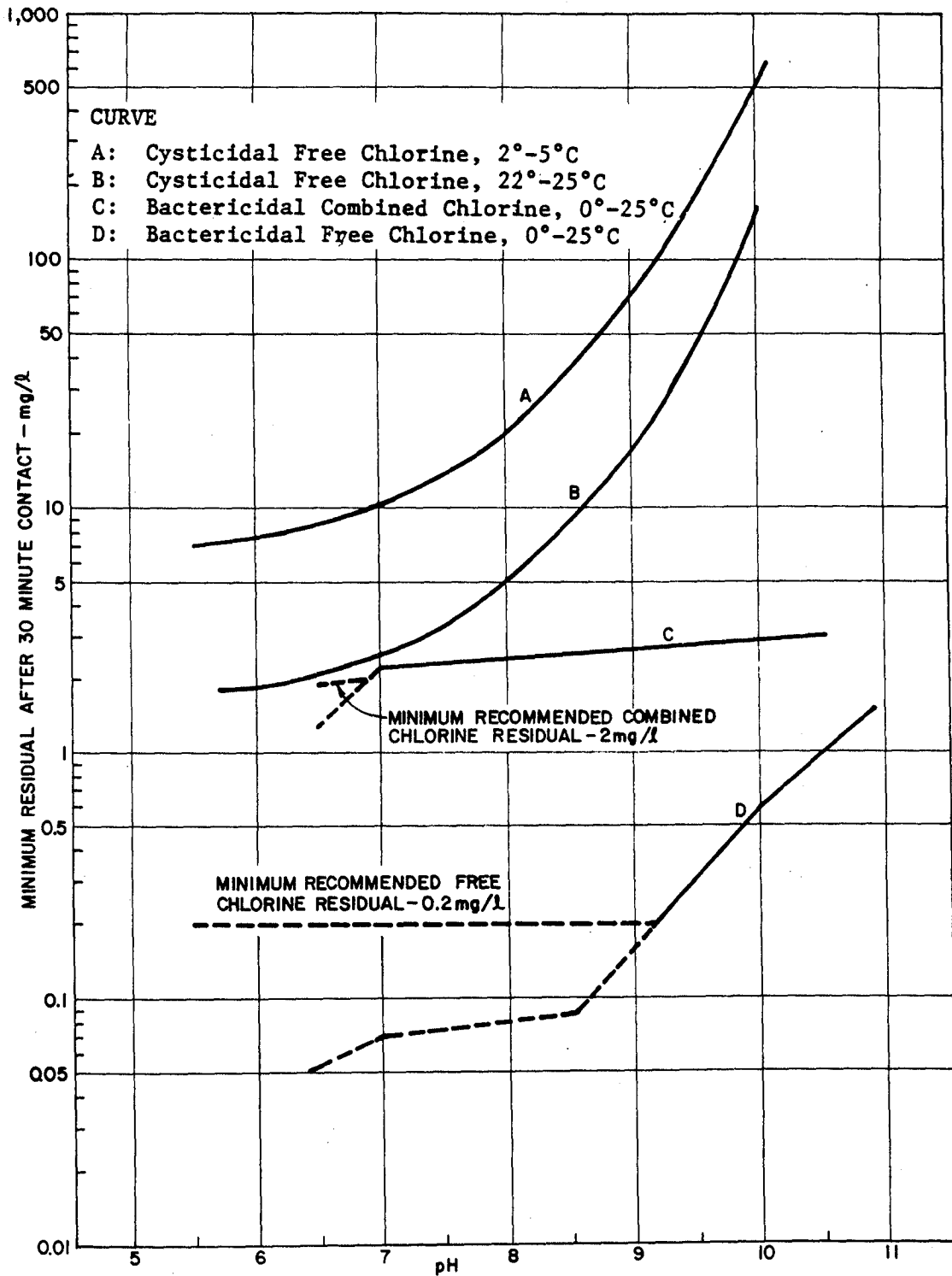
(1) Breakpoint chlorination. If water contains ammonia or certain nitrogenous organic matter which reacts with chlorine, the addition of chlorine causes the formation of chloramines until the ratio of elemental chlorine to ammonia compounds is about 5 to 1. Further addition of chlorine results in the oxidation of chloramines to gaseous nitrogen and nitrogen oxides, which decreases the quantity of chloramines present. After all of the chloramines have been oxidized, additional chlorine added to the water forms only free available chlorine. The point at which all of the chloramines have been oxidized and only free chlorine is formed is called the "breakpoint." If no ammonia is present in the water, there will be no breakpoint. The chlorine required to reach the breakpoint is usually about 10 times the ammonia nitrogen content of the water. However, in certain waters, because of the presence of other chlorine consuming substances, as much as 25 times the ammonia nitrogen concentration may be required. Enough chlorine should be added past the breakpoint to insure an adequate free chlorine residual.

(2) Marginal chlorination. Marginal chlorination involves the application of chlorine to produce a desired level of total chlorine residual regardless of the relative concentrations of free or combined chlorine present. In marginal chlorination, the initial chlorine demand has been satisfied, but some oxidizable substances remain.

(3) Chlorine dosages. Figure 3-4 provides minimum cysticidal and bactericidal free chlorine residuals and minimum bactericidal combined chlorine residuals for various pH and temperature levels. Since waterborne bacteria are the major concern at fixed installations, minimum bactericidal levels will be maintained in treated water in all parts of the distribution system under constant circulation. Even at lower pH levels, free chlorine residuals should not fall below 0.2 mg/l and combined chlorine residuals should not fall below 2.0 mg/l. If marginal chlorination is practiced, the total chlorine residual must not be less than 2.0 mg/l. Whenever epidemiological evidence indicates an outbreak of a nonbacterial waterborne disease such as amebiasis, infectious hepatitis, or schistosomiasis, cysticidal free chlorine residuals must be maintained in the water supply.

c. Other effects of chlorination. In addition to the disinfection achieved with chlorination, many other effects should be noted. Since the oxidizing power of chlorine is high, in the presence of free chlorine, hydrogen-sulfide is oxidized, nitrites are oxidized to nitrates, and soluble iron and manganese are oxidized to their insoluble states. Free chlorine also destroys many taste and odor producing substances. Many organic substances will react with chlorine to form chloro-organic compounds which may be objectionable either because of resultant tastes and odors or because of possible health effects.

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FIGURE 3-4. MINIMUM CHLORINE RESIDUALS

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d. Application of chlorine. Chlorine may be applied to water in one of two forms: as elemental chlorine or as hypochlorite salts. Hypochlorite salts should be used for water disinfection at all fixed installations unless it can be demonstrated that the use of elemental chlorine is more advantageous.

(1) Point of application. Chlorine may be applied to water in a variety of locations in the water treatment plant, storage facilities, or distribution system. It is absolutely essential that the chlorine applied to the water be quickly and thoroughly mixed with the water undergoing treatment. If required, special chlorine mixing facilities should be provided. In conventional water treatment plants, chlorine may be applied prior to any other treatment process (prechlorination), following one or more of the unit treatment processes (postchlorination), or in the more distant points of the distribution system (rechlorination).

(2) Chlorination equipment. Hypochlorite salts must be applied to the water in solution form. Hypochlorite solutions are pumped by a diaphragm pump through an injection system into the water to be chlorinated. If elemental chlorine is used for disinfection, it should be injected by solution-type chlorinators. Since chlorine solutions are corrosive, many components of a chlorination system must be constructed of corrosion resistant materials such as glass, silver, rubber, or plastics. Maintaining the chlorination apparatus in a trouble-free state is essential; therefore, key spare parts and repair kits for chlorination systems will be kept on hand.

(3) Automatic control. If automatic chlorination control is utilized, the chlorine feed rate should be controlled primarily by the rate of flow of water, with a signal from a downstream residual chlorine analyzer used to adjust the feed rate. Provision for manual control during emergency situations must be included.

e. Superchlorination and dechlorination. Superchlorination may be necessary if there are large variations in chlorine demand or if available contact time is brief. Water which has been superchlorinated generally requires dechlorination before delivery to the distribution system. Dechlorination may be achieved through the application of sulfur dioxide, sodium bisulfite, or sodium sulfite, or by passing the water through granular activated carbon filters. The dechlorination process (and subsequent rechlorination, if necessary) should be controlled so that the free residual chlorine remaining in the water is at least 0.2 mg/l.

f. Safety precautions for chlorination. The AWWA M3 contains safety recommendations regarding the use of chlorine. These recommendations will be followed at all Army water treatment facilities.



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3-8. Taste and odor control. Most taste and odors in surface water are caused by low concentrations of organic substances derived from decomposing vegetation, microscopic organisms, sewage and industrial waste pollution, etc. Treatment for taste and odor removal involves destruction of the odorous substance by chemical oxidation or its removal by aeration or adsorption by activated carbon.

a. Chemical oxidation. Chemical oxidizing agents which have been found effective and which can be used in the treatment of potable water are chlorine, chlorine dioxide, potassium permanganate, and ozone. No single chemical is completely effective under all operating conditions.

b. Aeration. Aeration is helpful in eliminating odor caused by hydrogen sulfide and other dissolved gases, but is ineffective in significantly reducing odor associated with dissolved organics.

c. Adsorption. Powdered activated carbon is commonly used for removal of odor by adsorption. The carbon can be applied to the water at any point in the treatment plant prior to filtration, but it is usually advisable to apply it early in the treatment process. Sometimes a split feed of carbon is employed with a portion applied to the raw water and a smaller amount to the filter influent. For maximum effectiveness, carbon should be applied well ahead of chlorination. The influent to a presedimentation basin is normally an effective carbon application point. Powdered carbon dosages usually range from 5 to 10 mg/l, but as much as 50 mg/l may be required under adverse conditions. Granular carbon has also been used for taste and odor removal. It has been employed as a separate treatment step in the form of carbon columns and as a substitute for sand in the filtration process. Used in this way, the granular carbon serves in a dual capacity as a filtration medium and for taste and odor removal.

### 3-9. Softening.

a. Applications. Softening of the entire base water supply will be considered only if the hardness exceeds 400 mg/l, expressed as equivalent  $\text{CaCO}_3$ . In this case, conventional softening techniques, which can be found in standard textbooks on water treatment processes should be considered. Softening to levels below 400 mg/l will only be performed on waters intended for the applications outlined in paragraphs (1) through (3) below. The cation ion exchange or zeolite process should be considered here unless other treatment methods are more feasible or necessary.

(1) Laundries. Water for laundries should have a hardness of 50 mg/l or less.

(2) Boilers. Boiler water for power plants and heating plants may require softening, but satisfactory results can often be obtained

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by application of corrosion and scale inhibitors such as sodium sulfite, sodium hexametaphosphate, and trisodium phosphate. Depending on the pressure at which the boiler is to operate, partial water-demineralization may also be necessary. See paragraph 3-12a for additional information on demineralization.

(3) Hospitals. When the water supplied to a hospital has a hardness of 170 mg/l or more, the water will be softened to approximately 50 mg/l. Where critical equipment requires water having a hardness of less than 50 mg/l, the most feasible means of obtaining that water quality will be used. Zero hardness water may be piped from the main softener or may be supplied from small individual softeners, whichever is the more feasible. The sodium content of the treated water must be taken into account when selecting a softening method for hospitals.

b. Cation exchange softening. Hardness is caused principally by the cations of calcium and magnesium, and cation exchange softening is accomplished by exchanging these ions for a cation, usually sodium, which does not contribute to hardness. This exchange is achieved by passage of the water through the bed of a granular sodium cation exchanger. This reaction is reversible and the exchanger can be regenerated with a strong solution of sodium chloride (common salt).

(1) Media used for ion exchange softening. Ion exchange water softeners should use polystyrene resins as the softening media. Such resins must have a hardness exchange capacity of at least 25,000 grains of hardness per cubic foot of resin.

(2) Regeneration of ion exchange softeners. The regeneration process generally involves three steps: (1) backwashing, (2) application of regenerating solutions, and (3) rinsing.

(a) Backwashing. The purposes of water softener backwashing are generally the same as the purposes of filter backwashing. Any turbidity particles filtered out of the water during softening are removed by the backwashing process. For polystyrene resin media, bed expansions of from 50 to 100 percent are normally required, which involve backflow rates of 4 to 10 gpm per square foot of bed area. Backwash periods generally range from 2 to 5 minutes. Ion exchange water softeners which operate upflow rather than downflow will not require backwashing, but the water to be softened must be virtually free of suspended matter.

(b) Application of salt brine. After the unit has been backwashed, a salt solution is applied to the medium in order to regenerate its softening capabilities. Regeneration brines should be 10 to 15 percent solutions of salt. The more salt used in the regeneration of a softener, the more complete the regeneration will be, and the greater the exchange capacity of the regenerated medium will

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be. Salt consumption commonly ranges from about 0.3- to 0.5-pound of salt per 1,000 grains of hardness removed. The contact time of the brine with the softening medium also has a direct effect on the exchange capacity of the regenerated medium. Contact times of 20 to 35 minutes will generally be used.

(c) Rinsing. After regeneration, the brine must be rinsed from the unit before softening is resumed. Backwash water, spent regenerant, and rinse water must be disposed of properly.

(3) Ion exchange water softeners. Although most ion exchange softeners at Army installations will be downflow pressure softeners, softening can also be achieved upflow. Larger ion exchange softening facilities are often operated upflow in order to avoid the necessity of backwashing. In general, ion exchange softeners are of two types: open gravity softeners and pressure softeners.

(a) Open gravity softeners. Open gravity softeners are constructed in much the same manner as rapid sand filters, and the modes of operation are very similar. However, the ion exchange medium used in open gravity softeners is much lighter than the sand used in filters, so backwash rates for open gravity softeners may also be operated upflow, but the softener will not achieve any filtering effects so the influent water must be virtually free of suspended matter.

(b) Pressure softeners. A polystyrene resin medium used for pressure softening should have a minimum bed depth of 24 inches and physical properties approximately the same as the following:

Shipping weight	45-55 pcf, net
Density	48-53 pcf
Moisture content	42-48 percent
Void volume	40 percent
Screen grading	16-50 mesh
Effective size	0.45-0.55 millimeter
Uniformity coefficient	<1.70
Fines through 50 mesh screen	<1 percent

If downflow softening is used, the flow rate through the softening medium may vary from 2 to 8 gpm per square foot but must not exceed 10 gpm per square foot under the most severe loadings. Severe reductions in exchange capacity are experienced if the softener operates at rates of flow in excess of 10 gpm per square foot for sustained periods of time. With upflow softening, the rate of flow should be adjusted to maintain a bed expansion of from 40 to 60 percent. The degree of bed expansion is a function of both the flow rate and the temperature of the influent water, so the flow rate must be decreased as water temperature decreases if a constant bed expansion is to be maintained.

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(4) Blending. An ion exchange softener operating properly will produce a water having a hardness approaching zero. Inasmuch as it is not generally economical nor desirable to soften all water to this low hardness level, provisions for blending the softened water with the unsoftened water are desirable.

(5) Other factors affecting ion exchange softening.

(a) Turbidity. Turbidity particles present in the water influent to the softener are deposited on the softening medium and may cause losses of exchange capacity and excessive head losses through the softener. If turbidity levels are excessive, the particles must be removed from the water prior to softening or special backwashing procedures must be implemented.

(b) Bacterial slimes. Unless proper disinfection is practiced, bacterial slimes can form in the softening medium and cause excessive head losses and loss of exchange capacity. These slimes can be prevented or removed through chlorination of feedwater or regeneration water.

(c) Temperature. The loss of head through a water softener is strongly affected by water temperature, with lower head losses occurring at higher temperatures. For example, at similar flow rates, the head loss through a softener at 122 degrees F. is only about 35 percent of what it would be at 36 degrees F. Also, the water temperature affects the exchange capacity of the softener, with a 10 to 15 percent increase at high operating temperatures (>86 degrees F.) over the exchange capacity at low temperatures (32 to 50 degrees F.).

(d) Iron, manganese, and aluminum. If iron, manganese, and aluminum are present in the influent water, precipitates may be formed which coat the ion exchange media particles and cause a loss of exchange capacity. This problem can be avoided through treatment to remove the iron, manganese, and aluminum from the water prior to softening.

(e) Total hardness and sodium concentration. If the total hardness exceeds 400 mg/l or the sodium salts, expressed as mg/l CaCO<sub>3</sub>, exceed 100 mg/l, the softener should be sized on the basis of the "compensated total hardness" rather than the total hardness. Compensated hardness is calculated from the equation:

$$TH_c = \frac{(TH) (9,000)}{9,000 - TC}$$

where:

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$TH_c$  = compensated hardness in mg/l as  $CaCO_3$

TH = total hardness in mg/l as  $CaCO_3$

TC = total cations in mg/l, all expressed as  $CaCO_3$

Compensated hardness ( $TH_c$ ) in mg/l is converted to grains per gallon by multiplying by 0.0584 or dividing by 17.1.

### 3-10. Iron and manganese control.

a. Occurrence of iron and manganese. Dissolved iron and manganese are encountered principally in ground waters devoid of dissolved oxygen. Normally, oxygenated surface waters do not contain significant concentrations of these metals; however, stagnant water, found in the bottom of thermally-stratified reservoirs, sometimes contains dissolved iron and manganese. Their presence in solution is associated with anaerobic conditions near the bottom of the reservoir.

b. Effects of iron and manganese. Dissolved iron in excess of 1 or 2 mg/l will cause an unpleasant taste, and on standing, the water will develop a cloudy appearance. Iron concentrations appreciably greater than 0.3 mg/l will cause red stains on plumbing fixtures and laundry. Similarly, manganese will cause black stains if present to the extent of more than about 0.05 mg/l. Deposits of iron and manganese can build up in water distribution systems and periodic "flush-outs" of these deposits result in objectionable color and turbidity at the consumer's tap.

c. Removal by oxidation and filtration. Oxidation can be accomplished with dissolved oxygen, added by aeration, and by the addition of an oxidizing chemical, such as chlorine, chlorine dioxide, potassium permanganate, or ozone. Manganese is more difficult than iron to oxidize and precipitate. In the absence of manganese, iron can often be removed with minimum treatment, consisting of aeration followed by direct filtration. In general, aeration alone will not oxidize manganese unless the pH is raised to about 9.5. Strong oxidants, such as chlorine or potassium permanganate, are effective at lower pH values. To insure oxidation, precipitation, and agglomeration of iron and manganese and their essentially complete removal, at least three treatment steps are usually necessary: aeration, contact time, and filtration. An aerator containing trays of coke, limestone, etc., is commonly used. Reaction time is provided by a contact or contact-sedimentation basin having a detention period of at least 30 minutes. Filtration is accomplished by conventional single or multi-media filters designed for a filtration rate of at least 3.0 gpm per square foot. The aeration step is frequently supplemented by a chemical oxidant, such as chlorine or permanganate. Flocculation is advantageous in the contact basin, particularly if iron exceeds about 2 mg/l.

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3-11. Corrosion and scale control. "Corrosion" can be defined as the deterioration of metal by direct chemical or electrochemical reaction with its environment. "Scale" refers to an accumulation of solids precipitated out of the water. In water treatment, corrosion and scale are closely associated. Both must be considered in connection with the design and operation of the treatment works. Thin scale may be desirable because it can provide a measure of protection against corrosion. However, thick layers of scale are detrimental in both hot and cold water systems. It is desirable to produce a "balanced" water that is neither highly corrosive nor excessively scale forming.

a. Corrosion.

(1) The extent and nature of corrosion reactions depend upon many factors. Among the most important are the chemical and physical nature of the water, its velocity, pipe metallurgy, and pipe coating. Controllable factors are principally calcium content, alkalinity, and pH. Certain corrosion inhibitors can also be used, but relatively few are suitable for potable water systems.

(2) Treatment to insure deposition and maintenance of a thin layer of calcium carbonate on the pipe interior is one widely used means of corrosion control. The rate of formation of calcium carbonate is favored by high concentrations of calcium and bicarbonate and carbonate alkalinity. Protection of this type cannot be attained in waters containing very low concentrations of calcium and alkalinity.

(3) Corrosion rates may also be reduced by the use of certain inhibitors. For potable water systems, the most practicable inhibitors are silicates and certain polyphosphate compounds.

(4) Dissolved oxygen and carbon dioxide have a significant effect on corrosion rates. Carbon dioxide lowers the pH and makes the water more aggressive.

(5) Corrosion rates are influenced to some extent by all mineral substances found in water, but corrosion effects are so interrelated that it is not possible to isolate the quantitative influence of individual ions. It is known that high concentrations of chloride and sulfate ions will produce increased corrosion rates. However, their adverse effects are somewhat mitigated by alkalinity (carbonate, bicarbonate) and calcium ions. Excessive calcium and alkalinity will often result in objectionable scale formation. It is, therefore, necessary to seek a compromise between corrosion on the one hand and scale formation on the other.

(6) Based on the corrosion accelerating effects of chloride and sulfate and the corrosion inhibiting effects of alkalinity, the following ratio, termed the "Corrosion Index," has been developed.

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$$\text{Corrosion Index} = \frac{[.02821] [\text{Cl}^-] + [.02083] [\text{SO}_4^{2-}]}{[.01639] [\text{HCO}_3^-]}$$

where:

$[\text{Cl}^-]$  = mg/l chloride ion as  $\text{Cl}^-$

$[\text{SO}_4^{2-}]$  = mg/l sulfate ion as  $\text{SO}_4^{2-}$

$[\text{HCO}_3^-]$  = mg/l bicarbonate ion as  $\text{HCO}_3^-$

For a pH range of about 7 to 8, and in the presence of dissolved oxygen, an index below about 0.1 indicates probable general freedom from corrosion. An index higher than 0.1 is indicative of corrosive tendencies. The higher the index, the greater the probability of corrosion.

b. Scale. Scale problems in distribution systems are caused principally by calcium carbonate, magnesium hydroxide, aluminum hydroxide, and the oxides and hydroxides of manganese and iron.

(1) Aluminum. Aluminum hydroxide deposits can result from excessive alum use for coagulation and/or improper coagulation practice, such as poor mixing and flocculation and incorrect coagulation pH.

(2) Magnesium. Magnesium hydroxide deposits have caused serious difficulties in distribution systems and hot water heaters. Magnesium solubility is highly sensitive to pH and temperature and failure to exercise careful control over its stabilization following softening will usually lead to deposition problems. It is advisable to maintain magnesium hardness below 40 mg/l and pH below 9.8. Hot water heaters should be operated so that water temperatures will not exceed 140 degrees F.

c. Chemical control of scale and corrosion. Corrosion protection of water system components can be achieved through the use of corrosion-resistant materials including plastics, copper, concrete, and cement-asbestos; the use of galvanized pipe; and the use of cement or coal-tar or calcite lined pipe. Chemical control by pH adjustment, and/or the addition of sodium silicate or polyphosphates to the water may be employed to supplement these protective measures if it is probable scale and/or corrosion will pose major problems to the water system components over the project design life. Chemical control can be expected to alleviate the problems but not necessarily eliminate them.

3-12. Special processes. In some cases, it will be necessary to use raw water supplies containing unacceptably large concentrations of constituents that cannot be removed by conventional treatment

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processes. The most common of these objectionable constituents are mineral salts, such as sulfates and chlorides, dissolved organic substances, and excess fluorides. Special treatment processes are necessary to remove these materials.

a. Demineralization. The presence of excessively high concentrations of dissolved materials in water is indicated by high chloride ( $\text{Cl}^-$ ), sulfate ( $\text{SO}_4^{2-}$ ), and total dissolved solids (TDS) levels. The limits for these substances for mobilization work are 250 mg/l, 250 mg/l, and 500 mg/l, respectively. These limits are based on esthetic considerations, and considerably higher concentrations, while not desirable, can be tolerated. Where demineralization is required, processes commonly employed are electrodialysis, reverse osmosis, distillation, and ion exchange. Waste brine solutions derived from these processes must be disposed of properly. All demineralization processes are energy intensive, and alternative water sources should be thoroughly investigated before a commitment to a demineralization project is made. If the demineralization process selected requires large inputs of electricity, consideration should be given to its operation principally during "off-peak" hours with storage of desalted water until needed.

b. Removal of dissolved organics. An effective means of removing dissolved organics is by their adsorption on granular activated carbon. Periodically, the granular carbon must be removed from the treatment system and reactivated in a special furnace. The carbon can serve as a filter medium as well as an adsorbent and is sometimes installed in conventional filters in place of the sand filter medium. Alternatively, the granular carbon may be employed in a special carbon contactor following conventional filtration. The granular carbon's effective size should be 0.7 to 1.0 millimeter; its uniformity coefficient,  $<1.9$ . When used in a filter, the carbon bed depth should be at least 2 feet and the corresponding hydraulic loading about 2 gpm per square foot. Where specially designed carbon contactors are provided following conventional filtration, 2- to 10-foot bed depths and hydraulic rates of about 5 gpm per square foot can be employed. The longer contact time provided by the deeper beds reduces reactivation frequency.

c. Excess fluoride removal. Fluoride concentration in excess of the limits stipulated in TB MED 576 pose a health hazard and must be removed. Fluoride removal can be accomplished by passage of the water through beds of activated alumina, bone char, or tricalcium phosphate, electrodialysis, reverse osmosis, or ion exchange. All removal processes produce liquid wastes and suitable provisions must be made for their disposal. Guidance as to the fluoride removal process to be employed can be obtained from laboratory studies of process effectiveness and fluoride removal capacity, using samples of the water that is to be treated.